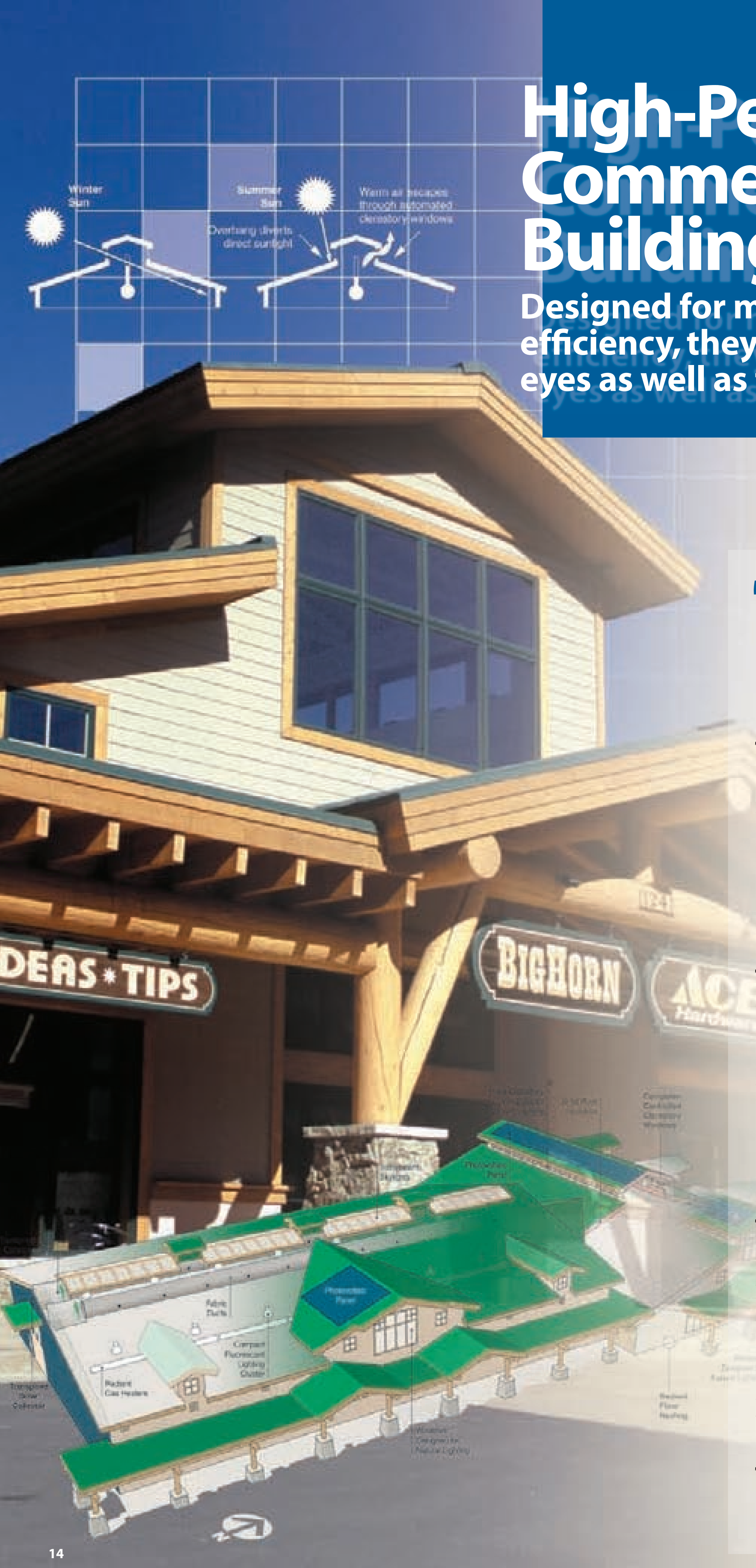


High-Performing Commercial Buildings

Designed for maximum energy efficiency, they are easy on the eyes as well as the budget

The buildings we live and work in consume about 39% of all the primary energy the nation uses annually—and 70% of the electricity. With energy costs on the rise, home and business owners need to know how to keep indoor areas comfortable without sending their energy bills through the roof.

To help meet that need, the engineers, architects, analysts, and programmers on the Commercial Building Integration (CBI) team in NREL's Center for Buildings and Thermal Systems study and design energy-efficient, high-performing commercial buildings. High-performing buildings are designed to provide superior levels of indoor comfort and lighting while consuming significantly less energy than those meeting minimum standards for energy efficiency.

The team monitors, analyzes, and documents how buildings actually perform. They make use of sophisticated building design software to simulate and analyze performance. And they support the U.S. Department of Energy (DOE) goal to have marketable zero-energy building designs ready by 2025. Zero-energy buildings produce at least as much energy as they consume. Thus, in addition to energy-efficient elements, these buildings incorporate energy-generating technologies such as photovoltaic (PV) solar electric systems.

The team's work reflects a system-integrated, "whole-building" approach to design. This means that they look carefully at how each element of a building will affect other elements, and the building as a whole, in terms of energy efficiency.

Six Good (Energy) Performers

CBI team leader Paul Torcellini says, "The best time to start thinking about a low- or zero-energy building is when you're designing the building envelope."

The envelope is the building's "skin"—walls, roofing, and other elements that together form a thermal barrier between the building and its environment. An energy-efficient envelope should provide most of the building's heating, ventilation, cooling (HVAC), and lighting needs.

Today, standard HVAC equipment (e.g., furnaces and air-conditioners) and electric lighting are usually required to supplement the work of an energy-efficient envelope. In the future, the envelope should supply most of the building's HVAC and lighting needs, with contributions from renewable energy. To move us closer to that future, the CBI team recently analyzed these six buildings:

- Adam Joseph Lewis Center for Environmental Studies, Oberlin College, Oberlin, Ohio
- BigHorn Home Improvement Center, Silverthorne, Colorado
- Cambria Office Building, Ebensburg, Pennsylvania
- Chesapeake Bay Foundation Philip Merrill Environmental Center, Annapolis, Maryland
- NREL Thermal Test Facility (TTF), Golden, Colorado
- Zion National Park Visitor Center Complex, Springdale, Utah.

Each one incorporates various energy efficiency and renewable energy design elements, such as daylighting (natural lighting), passive solar strategies, radiant heating, natural ventilation, evaporative cooling, ground-source heat pumps, and PV systems. NREL staff helped to design three of the six: the BigHorn Center, the TTF, and the Zion Visitor Center. They monitored all of them for a year or more when completed and analyzed data to compare actual energy performance with goals specified in original designs.

How the Buildings Measured Up

The thermal envelopes of all six buildings exceed those specified in ASHRAE Standard 90.1, published by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers. The buildings consume between 25% and 70% less energy than a comparable building would if designed to be ASHRAE code-compliant.

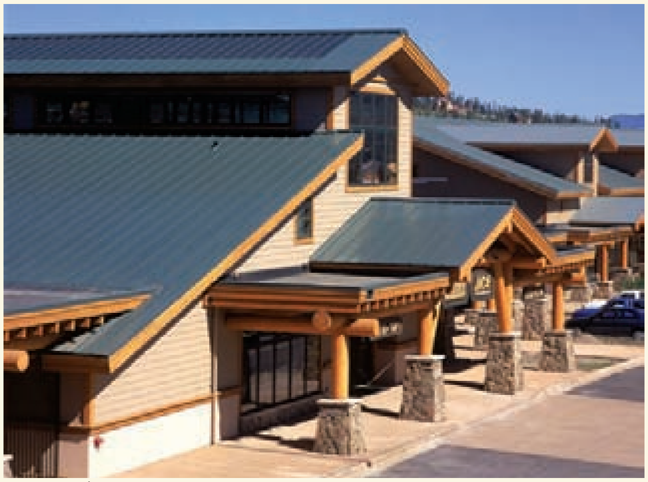
The monitoring revealed some gaps between design goals and actual performance, but later modifications helped to close those gaps. At the top of the list were problems with controls, insulation placement, and following the building plans. Here is a brief summary of the results of NREL's monitoring and analysis; see the table on page 17 for data from the six-building study.

Lewis Center. The Adam Joseph Lewis Center for Environmental Studies at Oberlin College in Ohio was designed to be an energy producer as well as an energy consumer and a teaching aid for students. The 13,600-ft^2 (1260-m^2) building, constructed in 2000, houses classrooms, offices, and an atrium. Features include passive solar design, daylighting, natural ventilation, an enhanced thermal envelope, and geothermal heat pumps for heating and cooling. A roof-integrated PV system provides electricity.

PIX10860/Robb Williamson

The Lewis Center for Environmental Studies at Oberlin College, Ohio

After construction, NREL staff monitored and evaluated the building's energy performance. The building uses 47% less energy than a comparable code-compliant one, and it demonstrates that a high-performance building works well even in a climate with high heating and cooling loads.



PIX09202/Jim Yost

The BigHorn Home Improvement Center, Silverthorne, Colorado

BigHorn Center. The BigHorn Development Project in Silverthorne, Colorado, is a retail complex in a mountain community. The building that NREL helped to design is a 36,980-ft^2 (3,436-m^2) structure housing a hardware store and a warehouse/lumberyard building. Calibrated simulations were used to estimate the performance of the building before construction. Monitoring and analysis since then show that the building has 53% lower energy costs than a typical code-compliant retail building of its size.

Daylighting and other design features reduced lighting energy requirements by 80%. Reducing electric lighting and controlling solar gains allowed the designers to use natural ventilation to meet the cooling load. An 8.9-kilowatt (kW) PV system initially provided 2.5% of the building's electricity needs. PV system and other improvements increased that to about 8%.

PIX10140/Jim Schafer

The Cambria Office Building in the Commonwealth of Pennsylvania Department of Environmental Protection, Ebensburg, Pennsylvania

Cambria Building. The Cambria office building in Ebensburg, Pennsylvania, is one of the high-performing buildings constructed for the Pennsylvania Department of Environmental Protection. Completed in 2000, it features efficient wall and roof insulation, high-performance windows,

PIX10884/Robb Williamson

The Chesapeake Bay Foundation Philip Merrill Environmental Center, Annapolis, Maryland

ground-source heat pumps, an under-floor air distribution system, energy recovery ventilators, and daylighting.

The design also specified an 18.2-kW PV system for on-site power production. These elements helped to achieve a LEED (Leadership in Energy and Environmental Design) 2.0 Gold Certification from the U.S. Green Building Council, and a 43% reduction in energy use in comparison to a standard building design. NREL staff collected performance data for comparison with a standard baseline computer model and then recommended further performance improvements.

Merrill Center. The Chesapeake Bay Foundation (CBF), dedicated to restoring and protecting the bay's resources, built the 31,000-ft^2 (2,880-m^2) Philip Merrill Environmental Center in Annapolis, Maryland, as its headquarters in 2000. The CBF incorporates many energy-saving features, including a ground-source heat pump to provide heat in winter and cooling in summer.

The building features large, south-facing windows for passive solar heating and daylighting. Sensors automatically dim lights when daylight levels are sufficient. Bay breezes provide natural ventilation. And an energy management system tracks outdoor temperatures and humidity to control the HVAC system. At CBF's request, NREL staff assessed the building's performance through a combination of monitoring and computer simulations; results showed a 12% annual energy cost savings compared with costs for a standard design.

The Zion National Park Visitor Center in Utah

PIX09243/Robb Williamson

Thermal Test Facility. NREL built the 10,000-ft^2 Thermal Test Facility (TTF) in 1996 to house buildings research and to refine and test a new integrated design process. The TTF's clerestory windows maximize the use of natural light and minimize summer cooling loads. A rigid exterior finish minimizes envelope heat transfer. A direct-indirect evaporative air-conditioning system meets cooling loads. And an energy management system monitors and controls internal temperatures, humidity, air pressure, duct pressure, light levels, and carbon dioxide levels.

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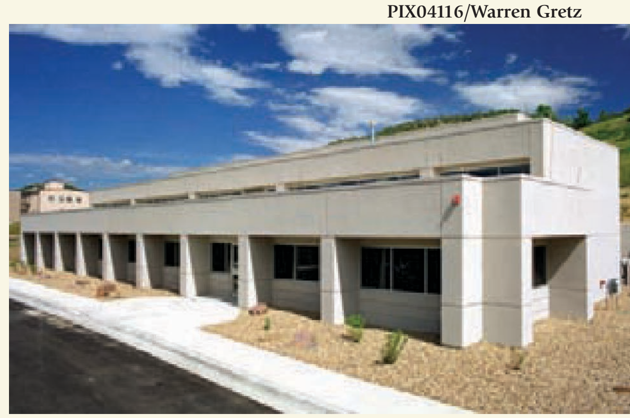

NREL's Thermal Test Facility, Golden, Colorado

Using computer simulations, NREL tested several design concepts before construction. The goal was to reduce building energy requirements by 70%. After construction, simulated performance was compared with actual performance; results included energy cost savings of 51%.

Zion Visitor Center. To develop a new visitor center complex in Zion National Park in southwestern Utah, the National Park Service requested technical support from NREL. Their collaboration lasted throughout the design, construction, and evaluation phases.

The 8,800-ft^2 (817-m^2) main building that opened in May 2000 houses interpretative displays, offices, and retail space. Features include passive direct evaporative cooling, natural ventilation, external shading devices, and glazing that minimizes solar gain in summer and uses it in winter. Also featured are thermal mass sized for the direct-gain system, a Trombe wall, daylighting, PV power, and digital controls to integrate energy operations. The building has 67% lower energy costs than a similar one meeting applicable energy codes.

Summary of energy savings for the six buildings studied

Metric		Oberlin	Zion	Cambria	CBF	TTF[1]	BigHorn
Benchmark	ASHRAE Standard 90.1 Version	2001	1995[2]	2001	2001	1995[2]	2001
Savings[3]	Net Source Energy Savings[4]	79%	65%	42%	22%	45%	54%
	Net Site Energy Savings[5]	79%	65%	42%	25%	42%	36%
	Site Energy Savings[6]	47%	62%	40%	25%	42%	35%
	Energy Cost Savings	35%	67%	43%	12%	51%	53%
Project Goal Comparison	Design Goal or Predicted Performance	Net Site Energy Use: 0.0 kBtu/ft^2·yr	Energy Cost Saving: 80%[7]	Energy Cost Saving: 66%[7]	LEED 1.0 Platinum Rating	Energy Cost Saving: 70%[7]	Energy Cost Saving: 60%[7]
	Measured or Simulated Performance	Net Site Energy Use: 16.4 kBtu/ft^2·yr	Energy Cost Saving: 67%	Energy Cost Saving: 44%	LEED 1.0 Platinum Rating	Energy Cost Saving: 51%	Energy Cost Saving: 53%

1 TTF monitored for select periods; actual data used to calibrate simulations.

2 Code used was 1995 Federal Energy Code, 10 CFR 435 (DOE 1995); based on ASHRAE 90.1-1989 with more stringent lighting power densities.

3 Energy savings for Oberlin, Bighorn, TTF, and Cambria calculated with simulations of as-built and base-case buildings with typical weather data; Zion and CBF savings calculated with measured data and base-case simulations run with measured weather data.

4 Source energy is the energy required to supply energy in the form it is used at the site; the Cambria office building purchases 100% green power, so source energy could be calculated assuming 9% loss for transmission and distribution (EIA 2004).

5 Net site energy use allows credit for electricity generated on site by the PV system.

6 Total site energy use is the total electricity consumed.

7 Predicted energy costs, calculated before construction, may not indicate future performance because of volatile energy prices.

Selected Best Practices

The results of this study suggested several best practices for high-performing buildings:

- Use an integrated design process to system-engineer the building
- Use computer simulations to guide the design process; these help designers analyze trade-offs and examine the energy impacts of architecture and HVAC choices
- Simulate and measure the building's energy performance at design, construction, and occupancy stages
- Set specific, quantifiable energy performance goals
- Design the building envelope to meet or minimize as many HVAC and lighting loads as possible
- Size HVAC and lighting systems to meet loads not met by the envelope
- Use daylighting in all zones adjacent to exterior walls or roofs
- Install highly reflective surfaces in all daylit zones, especially ceilings
- Monitor and evaluate post-occupancy energy performance
- Implement standardized measurement procedures using standard metrics
- Carefully design and implement the use, control, and integration of economizers, natural ventilation, and energy recovery ventilators.

Practices like these can move us closer to new commercial buildings that save considerable energy and produce it, as well.

For more information, contact Paul Torcellini, Commercial Building Integration Team Leader, Paul_Torcellini@nrel.gov, and see www.nrel.gov/buildings/highperformance/.

Paul Torcellini examines an in-floor diffuser for the raised-floor air distribution system in the Cambria office building in Pennsylvania.

PIX11001/Robb Williamson